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EFFECTS OF ACIDIC PRECIPITATION AND RELATED POLLUTANTS IN THE TERRESTRIAL ENVIRONMENT

A PROGRAM DESCRIPTION

ARB-218-87-Phyto

APIOS-008-88

JULY 1988

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Ministry
of the
Environment

Ontario

Jim Bradley
Minister

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By: W.D. McIlveen

S.N. Linzon

Air Resources Branch

Ontario Ministry of the Environment

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Effets des précipitations acides et des polluants apparentés sur l'environnement terrestre : présentation du programme

Il incombe au ministère de l'Environnement de l'Ontario de contrôler les effets des précipitations acides et des polluants apparentés sur l'environnement. Dans le cadre de l'Étude sur les précipitations acides en Ontario (APIOS), un programme visant à évaluer les effets de ces polluants sur l'environnement terrestre a été créé. Nous avons établi les mécanismes susceptibles d'avoir des conséquences sur l'environnement et formulé une série de questions d'ordre scientifique relatives à ces conséquences éventuelles. Nous avons ensuite créé une série d'études sur les composants pour tenter de fournir des réponses à ces questions scientifiques. Le présent rapport résume les objectifs et les résultats prévus de chacune des études ainsi que les réalisations jusqu'à présent.

I PREAMBLE

Under the Environmental Protection Act, the Government of Ontario established that the Ontario Ministry of the Environment would provide for the protection and conservation of the natural environment within the Province. This protection applies to property, plant and animal life. Thus, when pollutants of anthropogenic origin (including acidic precipitation and photochemical oxidants) were suggested as having a role in the deterioration of North American crops and forests, the Ontario Ministry of the Environment initiated investigations into this problem. This was carried out under the auspices of the Acid Precipitation in Ontario Study (APIOS) of the Ministry of the Environment. This document outlines the objectives and scope of those programs being conducted in the terrestrial portions of the natural environment.

II PROVINCIAL OBJECTIVES OF ACIDIC RAIN STUDIES IN THE TERRESTRIAL ENVIRONMENT

1. To determine the impact (if any) of acidic precipitation and related pollutants on the terrestrial environment.

2. To provide appropriate documentation for sound abatement strategies where applicable.

3. To co-operate with similar agencies of other jurisdictions to examine the problems in a coordinated manner.

III THE TERRESTRIAL ENVIRONMENT

The terrestrial environment is extremely complex (and naturally variable, having many components in continuously changing states and stages). It has been greatly influenced by human activity which has altered land use for agriculture and urbanization. The natural forested areas have been disturbed to varying degrees by lumbering and other interests. It is therefore difficult to separate those changes associated with natural processes from those created by the advancement of civilization, especially where undesirable by-products or pollutants are involved.

To determine if pollutants, in any form, are having an effect on the environment, then the "normal" condition should be known and used as a basis for comparison. Unfortunately, very little is known about many natural systems and baseline information is mostly non-existent, especially where long-term effects are in question. All current studies are undertaken with the understanding that the limitations noted above are involved to some degree.

IV PRIMARY COMPONENTS OF THE TERRESTRIAL ENVIRONMENT

The terrestrial environment can be considered to be composed of "non-living" and "living" components. The "non-living" consists of soil, rocks, minerals and detritus. The living components can generally be grouped into vegetation (higher plants, ferns, lichens, mosses, fungi and bacteria) and animals (mammals, reptiles, birds, amphibians and invertebrates of many types). All of these fit into an intricate network of relationships among themselves and the environment. Disruption of one facet of the network usually results in a disruption of a larger part of the entire system. A simplified model of the primary processes occurring in the terrestrial environment are shown in Figure 1.

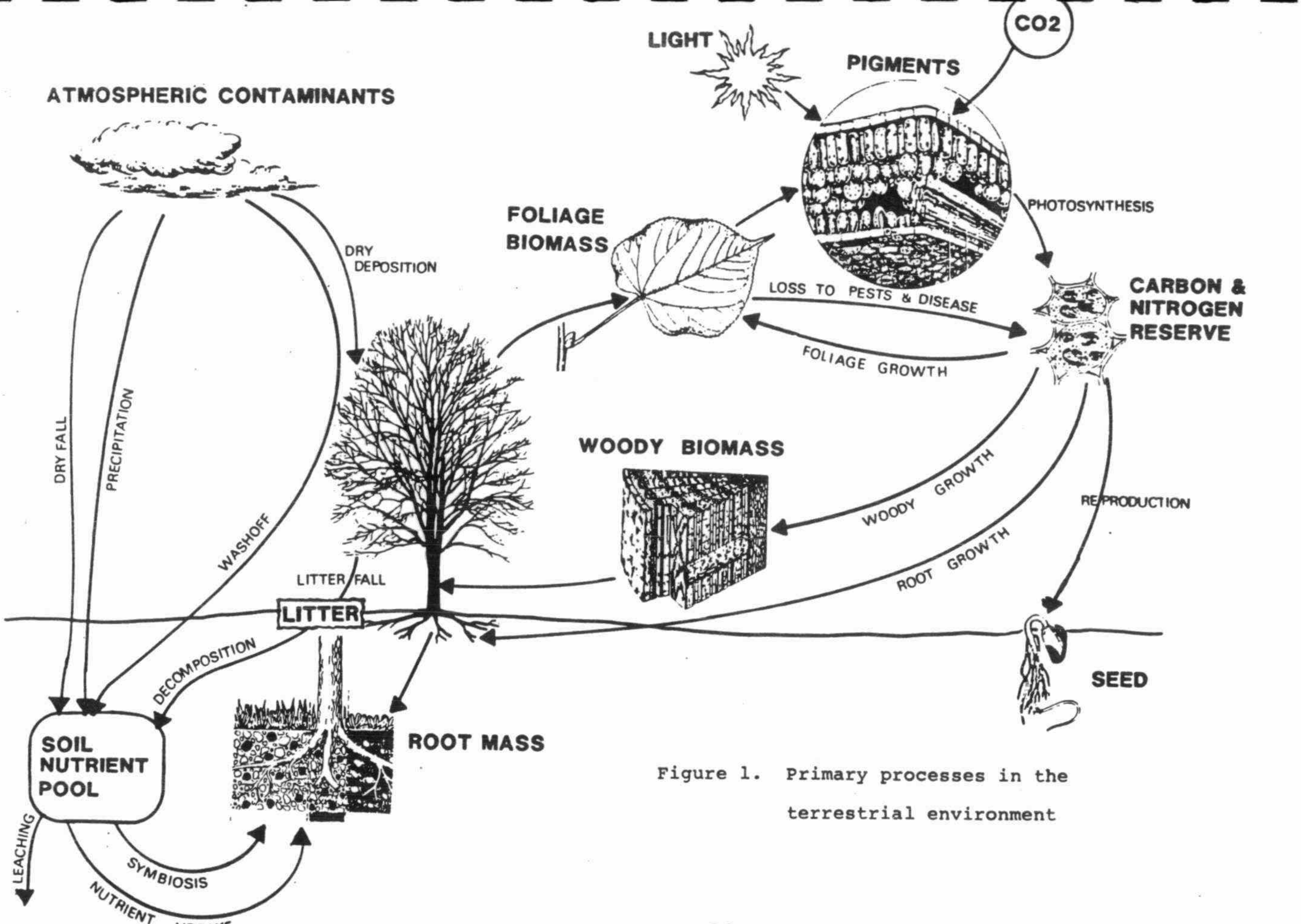


Figure 1. Primary processes in the terrestrial environment

V IMPACT OF POLLUTANTS ON THE TERRESTRIAL ENVIRONMENT

An impact of pollutants is of concern when any component of the natural environment is altered in number, condition, or in its ability to reproduce by a measurable amount (greater or lesser than "normal"). This serves as our definition of impact. The nature and degree of the impact must be assessed before any action is taken to eliminate or minimize that impact. Some of the main factors affecting sensitivity of the terrestrial environment to pollutants are listed in Appendix 1 and Appendix 2. Some typical methods of measuring impact of pollutants are listed in Appendix 3.

VI THE HYPOTHESIS

In order to determine if there is an impact of pollutants in the environment, it is necessary to establish a testable hypothesis. In this case (i.e., Acidic precipitation), the null hypothesis is "Acidic precipitation and related pollutants are not creating an impact or effect on components of the terrestrial environment."

The null hypothesis is rejected when measurements show a measurable difference statistically different at the 0.05 level of probability.

VII SCOPE OF THE STUDIES

While it is recognized that all of the primary components are integral parts of the environment, resource limitations dictate that only major components of the terrestrial system can be investigated. Initially these studies will be restricted to soils and higher plants since these form the greater portion of the environment by mass.

Soil Studies will be limited to those soils supporting vegetative growth to a depth representing the root development zones.

Vegetation Studies will be limited to forest trees and agricultural crops (Appendix 4). It is recognized that other types of vegetation exist; however, they present another set of difficulties which must be addressed at a later time.

VIII APPROACHES TO STUDY THE PROBLEM

Even by restricting the scope of the problem to the topics noted above, the study of the effects of pollutants on the terrestrial environment is too large to manage as a single project. It is therefore necessary to break down the study into smaller components which are more manageable. The identification of these smaller components is made on the basis of:

i) current understanding of biological systems
ii) indirect versus direct effects of pollutants
iii) principal crop and forest species
iv) probability for an effect of a pollutant
v) ability to measure an effect

Each smaller component can be divided into smaller sub-components for more detailed examination.

After sufficient knowledge of the individual small components has been accumulated, it will be necessary to synthesize the information in an overall picture of the problem. It is necessary to first complete Provincial Objective 1 (p. 1) before any efforts towards Objective 2 can be realized. Objective 3 will aid in reducing time and effort in achieving the first two objectives.

IX SCIENTIFIC QUESTIONS

The study of the role of acidic precipitation in the terrestrial system can be guided by searching for answers to some general questions. The questions were developed by examining the process outlined in Figure 1. The following scientific questions are applicable to the Ontario situation:

1. Are changes in growth and mortality and the presence of unusual foliar symptomatology in sugar maple and other hardwoods greater than can be attributed to typical trends and levels of natural variability?

2. What spatial patterns, if any, exist in growth and mortality and in the presence of unusual symptomatology in forests and how do these patterns relate to spatial patterns of pollutant exposure?

3. What is the effect of sulfur and/or nitrogen derived pollutants on sugar maple, white spruce, hybrid poplar and agricultural crops through indirect or direct toxicity to roots, mycorrhizae or soil microbial populations by the mobilization of metals?

4. What is the effect of sulfur and/or nitrogen derived pollutants, alone or in combination with oxidants, on sugar maple, hybrid poplar, white spruce and agricultural crops through the mechanism of increased leaching of foliar nutrients?

5. What is the effect of sulfur and/or nitrogen derived pollutants, alone or in combination with oxidants, on sugar maple, hybrid poplar, white spruce and agricultural crops morphology by the mechanism of carbon allocation and physiological processes?

6. What is the effect of nitrogen compounds alone or in combination with oxidants on sugar maple, white spruce, hybrid poplar and agricultural crops through the mechanism of increased winter damage due to altered physiology?

7. What is the effect of sulfur and/or nitrogen derived pollutants alone, or in combination with oxidants, on forest species and agricultural crops through mechanism of disrupting reproduction or regeneration?

8. What is the effect of sulfur and/or nitrogen derived pollutants, alone or in combination with oxidants, on forest species and agricultural crops through the mechanism of altered susceptibility to insects and pathogens?

9. What is the role of sulfur and/or nitrogen derived pollutants on soil chemistry including recycling of nutrients through litter decomposition?

X PROGRAM MANAGEMENT AND ORGANIZATION

The Acidic Precipitation in Ontario Study (APIOS) is a Provincial goal-oriented research and monitoring program. It is sponsored and funded by the Ontario Ministry of the Environment. The purpose of the APIOS Co-ordination Office is to coordinate all acid precipitation-related studies in the Province of Ontario.

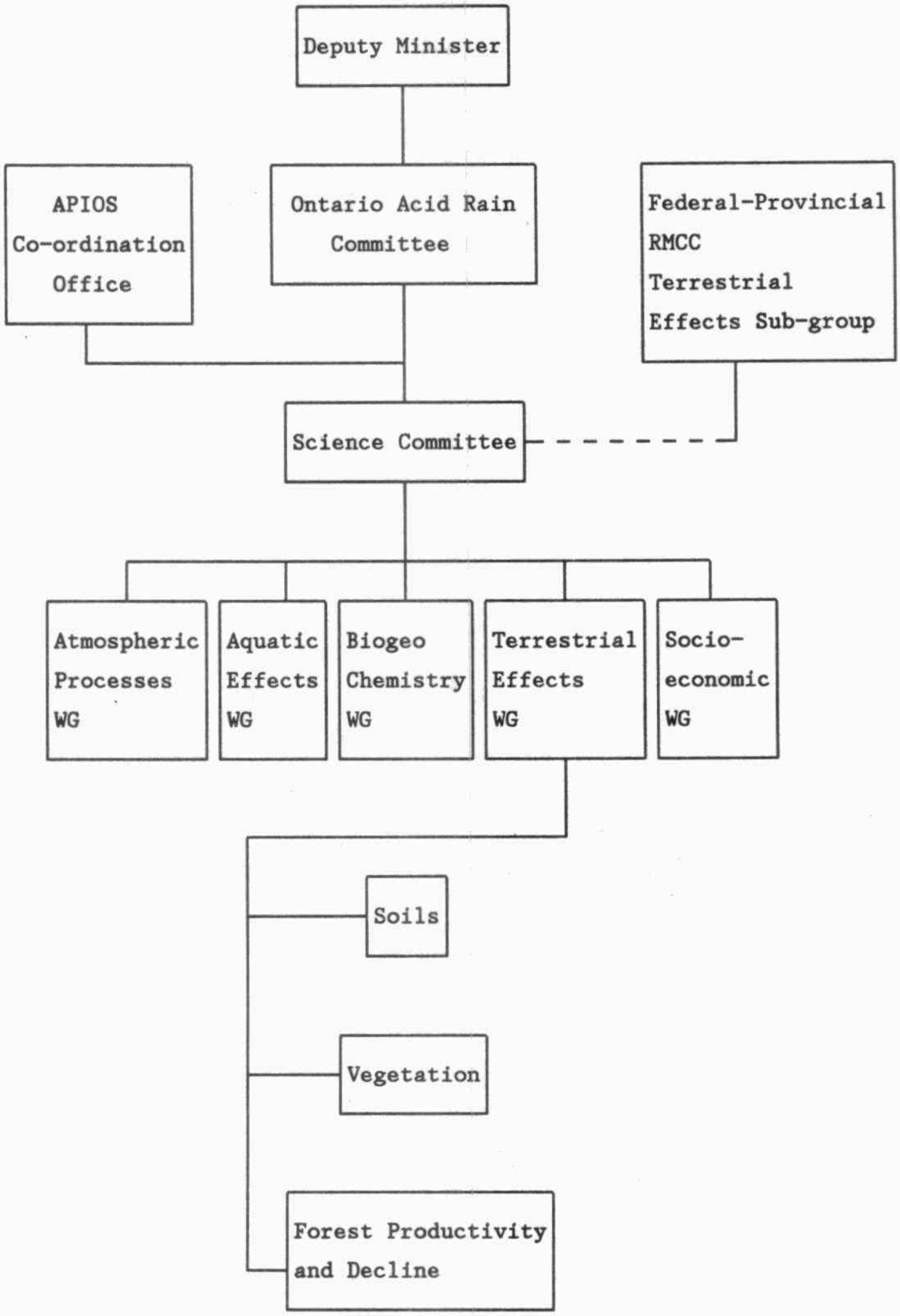
The activities of APIOS have been structured into several working groups, each of which deals with general topic areas:

1. Atmospheric Processes
2. Aquatic Effects
3. Terrestrial Effects
4. Biogeochemistry
5. Socioeconomic Effects

Each of these working groups is represented on the Science Committee as shown in Figure 2. Management of the Terrestrial Effects program is carried out by staff of the Phytotoxicology Section, Air Resources Branch, Ontario Ministry of the Environment. Some component studies are carried out by Ministry staff while other studies are being completed by private or university consultants under contract. Co-operation and information is exchanged with the Ontario Ministries of Natural Resources and Agriculture and Food as well as the Canadian Forestry Service and the Canadian Atmospheric Environment Service.

Co-ordination of research efforts across Canada is facilitated through the Federal-Provincial Research and Monitoring Coordination Committee (RMCC).

Fig. 2 ORGANIZATIONAL STRUCTURE OF TERRESTRIAL EFFECTS PROGRAM



XI COMPONENT STUDIES

The Terrestrial Effects program has been divided into 3 component parts, namely, soils, vegetation and forest productivity and decline. These in turn have smaller component studies. A description of each of the smaller studies currently being carried out is summarized below together with the number of the Scientific Question for which an answer is required. To date, the question involving reproduction has not been addressed under the APIOS program.

	COMPONENT STUDY														
	Soils				Vegetation		Forest Decline								
Scientific Question	a	b	c	d	a	b	a	b	c	d	e	f	g	h	i
1						X	X								X
2	X	X	X	X				X	X					X	X
3	X						X					X			
4					X	X					X				
5						X	X		X		X		X		
6						X					X		X		
7*															
8						X	X			X					
9			X									X			

*No studies to date.

Soil Studies

a) Baseline Sampling

Objectives: To determine the baseline status of chemical and physical properties of Ontario soils for future reassessment. To establish a reliable database for Ontario soils for use in soil sensitivity experiments and mapping.

Anticipated Results: Baseline sampling will provide a data base against which future changes caused by long-range atmospheric deposition may be detected. Such changes may have long-term adverse effects on forest productivity and aquatic systems. This database will be incorporated into soil sensitivity mapping.

Achievements: Towards this end, the present chemical and physical state of the soils at over 400 permanent soils sites on various landforms has been established throughout Ontario. Re-sampling at selected sites will be performed periodically at various time intervals.

The precise location of each site was recorded and duplicate soil samples were collected from every horizon from a soil pit approximately 1m in depth. Information such as soil colour, number and depth of roots, stones, and soil structure were recorded also in the field. The soil samples were analyzed for 25 different parameters including texture, pH, base saturation, cation exchange capacity, organic matter, iron, aluminum, trace metals, S and N. Baseline soil data for the 1980-81 sampling period appear in a 3 volume report entitled "Ontario Soil Baseline Survey Analytical Data 1980-81". A second edition of this report containing soil data for the 1982-83 sampling period is expected in 1988.

Scientific Question(s): 2,3

b) Soil Sensitivity Mapping

Objectives: To develop criteria for assessing soil sensitivity to acidic precipitation.

To prepare soil sensitivity maps for Ontario with respect to forest productivity and aquatic systems using Soil Baseline Survey data.

Anticipated Results: Soil sensitivity maps based on soil sensitivity criteria will be used to delineate areas of potential damage by acidic deposition. These findings may be used in the development of abatement strategies.

Achievements: A report entitled "Preliminary mapping of soils sensitive to acid precipitation in Northeastern Ontario" was completed in 1981. Soil analytical data from the baseline study have been used to generate maps of soil data for Ontario. Soil sensitivity data have been used to "ground truth" maps of "The potential of soils and geology to reduce the acidity of incoming acidic deposition" prepared by the Lands Directorate, Environment Canada. These maps and an accompanying report have been jointly published by the Ontario Ministry of the Environment and the Lands Directorate. These maps also provide a useful indicator of regional aquatic sensitivity in Ontario.

Scientific Question(s): 2

c) Site Variability Study

Objective: To document the natural variation in soil chemical and physical parameters.

Anticipated Results: The study provides a measure of the statistical reliability of results of soil sampling for use in interpretation of baseline soils data.

Achievements: Two existing baseline soil sites near Dorset were systematically re-sampled on a 10m grid to evaluate seasonal and spatial variations. A report on the results of this study is in preparation.

Scientific Question(s): 2, 9

d) Open-Top Soil Columns

Objective: To determine the long-term changes in soil exposed to ambient conditions.

Anticipated Results: The data will be used to predict the effect of different acid loadings on different types of soil. These predictions may have a bearing on the choice of abatement strategy.

Achievements: To determine the long-term chemical changes in soil exposed to ambient conditions, three different soil types (sand, silt, clay) were collected, chemically analyzed and placed into open-top columns. Several replicates of each soil type were placed in the field in the Northwestern and Northeastern Regions, and in southern Ontario. A replicate column of each of the three soil types will be removed from the ground after 5,10,15 and 20 year intervals and chemically analyzed to determine changes in soil chemistry under ambient conditions.

Scientific Question(s): 2,

Vegetation Studies

a) Baseline Sampling

Objective: To establish the baseline status for nutrient and selected trace elements in tree foliage for future reassessment.

Anticipated Results: Foliage chemistry can be used to evaluate nutrient shortages or elevations of toxic elements which may be related to acidic deposition. Present-day foliage chemistry can be used as a baseline against which future trends can be evaluated.

Achievements: Twelve baseline sites were established in Southern Ontario in 1980-81. One site was intensively sampled in 1982 to provide information on a seasonal elemental variability of the foliage and spatial variability in the tree canopy. A report will be prepared that will compare 1987 data with earlier collections.

In the Northwestern Region, field work was completed in 1981 for the first round of sampling. Data from 50 sites are currently being evaluated.

A series of vegetation foliage samples was collected from 12 species at 14 locations within the High Falls biogeochemical study area.

Scientific Question 4

b) Simulated Acid Rain Experiments

Objectives: To design, construct and operate special indoor rain chambers and outdoor rain exclusion canopies for conducting simulated acid rain experiments with plants.

To perform greenhouse and field experiments with simulated acid rain in order to investigate the potential effects of increased rain acidity, alone or in combination with other air pollutants, on agricultural crops and forest species under controlled conditions.

Anticipated Results: Reproducible, simulated rain events will provide reliable results under both greenhouse and field conditions yielding information on injury symptoms to plants, threshold levels of acidity causing effects to plants, relative sensitivities and/or response characteristics for selected plant species. Additional knowledge will be gained on the interactive effects between acid rain and SO_2, O_3, nutrient deficiencies, drought and disease stresses.

Achievements: Four indoor rain simulation chambers were constructed in 1982 and have been utilized in simulated acid rain experiments with greenhouse-grown plants (e.g. pinto bean, soybean, radish, petunia, tobacco, alfalfa, barley, cabbage, cucumber, corn, tomato, white birch, sugar maple, white pine, white spruce). A report on these simulated rain experiments is pending.

A fully-automated rain exclusion canopy and gaseous pollutant exposure system was completed in 1984 after two years of construction. To determine the dose-response characteristics of soybean and radish, a trial field experiment was conducted in 1984. Improvements to the system were made and in the 1985 and 1986 field season, crops of Hogson soybeans were grown. Beginning in 1987, the system was devoted to studies of acidic precipitation effects on tree species including sugar maple, white spruce and hybrid poplar.

Scientific Questions: 1, 4, 5, 6, 8

Forest Productivity and Decline Studies

a) Maple Decline Study

Objective: To determine the role that acidic precipitation is playing in the decline of sugar maples trees in the Muskoka - Parry Sound Districts of Ontario.

Anticipated Results: Possible causes of the decline of sugar maple trees on the study woodlots will be deduced from site quality data, climate records, management practices and histories of disease and insect defoliations. The elemental composition database generated from foliage, soil, twig and root sampling will aid in the interpretation of the physiological response of these trees to environmental stresses such as acidic deposition.

Achievements: A total of eight sites was selected for the study in 1984, seven of which were in the Muskoka-Parry Sound district of southern Ontario. One site in the Northwestern Region near Thunder Bay served as a check being located outside the zone of heavy acidic atmospheric deposition. In 1985, three additional sites were established. Two were in the Peterborough area located on calcareous soil and the third was in an uncut mature hardwood stand in the interior of Algonquin Park composed of very old trees (over 300 years) which had not been severely affected by forest tent caterpillar infestations. The three new sites were evaluated and sampled in the same manner as the 1984 locations.

At each site, permanent observation plots were established to determine the incidence and degree of tree decline. Adjacent to each plot, trees in various ages of decline were selected for sampling purposes. Foliage, roots, increment cores and associated soil were collected from each of the sampling trees for chemical analysis. In addition, soil samples collected from a soil pit at each site will be used to assess the sensitivity of the soil to acidic precipitation. Acidic atmospheric deposition rates, climatic records, management practices, history of disease and insect defoliation, site disturbance, tree age and site quality will be investigated at each of the sites to determine the role that acidic deposition is playing in the decline of sugar maple trees in Ontario. A detailed report incorporating the results to date will be finalized in 1988.

Scientific Question(s): 1, 3, 5, 8

b) Hardwood Decline Survey

Objective: To determine the incidence, degree and extent of decline in hardwood stands across the Province of Ontario.

To monitor changes in decline symptoms in the hardwood stands.

Anticipated Results: The survey will produce documentation of the current status of hardwood forest stands across the Province with respect to decline symptoms. Interpretation of the data will assist in determining the extent of the problem and aid in elucidating the role of environmental stresses in the decline syndrome.

Achievements: One hundred and ten permanent observation plots have been established in the Great Lakes - St. Lawrence and the Deciduous forest regions. At each plot, trees were assessed and assigned a "decline index" based on dead branches, leaf chlorosis, and undersized leaves. At 35 of these sites, maple foliage and soil samples were collected and chemically analyzed. Site quality and anthropogenic factors are being considered at each site in relation to tree condition. Sites will be reassessed periodically to monitor changes in forest condition.

Scientific Question(s): 2

c) Dendrochronology Study

Objectives: To develop growth chronologies for sugar maple in the Province of Ontario.

To establish trends in growth which might reflect changes in environmental conditions.

Anticipated Results: Growth patterns of sugar maple subjected to various environmental conditions will provide insight into the role and process of those conditions on the health and welfare of forest species.

Achievements: At 54 sugar maple plots in 3 major forest sections (Upper St. Lawrence, Algonquin Pontiac and Algoma) in the Great Lakes - St. Lawrence Forest Region, increment cores have been taken to examine growth patterns in sugar maple trees. At 27 of these plots, whole trees have been harvested for stem analysis in order to determine growth chronologies for sugar maple. The sampling portion of this study is complete and data are being processed using a Tree Ring Increment Measuring (TRIM) System.

Scientific Question(s): 2, 5

d) Pathology

Objective: To determine the role of disease agents in the decline of sugar maple stands.

Anticipated Results: The study will systematically examine groups of organisms which have the potential to kill or weaken trees. The result should identify those organism(s) which might be involved in the decline syndrome.

Achievements: A study to examine two groups of organisms including plant-parasitic nematodes and mycoplasma-like organisms and their role in maple decline has been initiated.

Scientific Questions(s): 8

e) Early Diagnosis of Forest Decline

Objective: To develop a means of diagnosing forest decline prior to the appearance of visible dieback symptoms on forest trees by making vegetative tests using physiological or biochemical characteristics of tree tissues.

Anticipated Results: Selection of appropriate test parameters may allow the identification of trees subjected to various environmental stresses before any symptoms of injury become apparent thereby allowing time to address remedial measures.

Achievements: Staff of the Ontario Ministry of the Environment participated in trial studies in England in April, 1986 and in field sampling in West Germany in August, 1986. Comparable tests were conducted on tree species in Ontario in 1987.

Scientific Questions(s): 4, 5, 6

f) Root Physiology

Objective: To investigate action of constituent chemical elements in soil on the physiology of plant roots with respect to their role in decline of forest trees.

Anticipated Results: The role of nutrient ions such as calcium, magnesium and potassium as well as aluminum, at the soil-root interface will be documented. A full understanding of these chemical processes is required to adequately address the prospects for taking mitigative measures against acidification of soil or other alternative approaches.

Achievements: Some studies of tree decline in Europe have implicated nutrient imbalances in the soil. The role of nutrient ions in the case of sugar maple is poorly known. In 1987, the Ontario Ministry of the Environment funded a study of root physiology regarding this problem area.

Scientific Questions(s): 3, 9

g) Carbohydrate and Nitrogen Storage

Objective: To determine whether stored reserves of carbohydrates such as starch or sugar or nitrogen compounds vitally important to perennial species such as trees are impaired in trees species subjected to various stresses including acidic precipitation.

Anticipated Results: Without reserves of energy, the plant would not be able to survive the winter or to produce a new flush of growth in the following year (especially noteworthy for sugar maple where trees are tapped to obtain some of this stored energy in maple syrup production). The study will help to establish critical concentrations of reserves for survival of trees.

Achievements: An assessment of stored carbohydrate in sugar maple trees at selected plot locations in the Muskoka area was initiated in 1987. Sap samples will be collected from trees showing various degrees of decline each spring and samples of root tissues will be collected each spring and fall for several years. The samples will be analysed for sugar and starch. The location of the study plots is in an area where an infestation by tent caterpillar is expected within the next several years. By monitoring stored energy reserves and insect attacks, it may be possible to relate tree survival to at least a few of the environmental variables.

Measurements of energy reserves will also be made in the tissues of trees exposed to simulated acidic precipitation rain exclusion canopy system.

Scientific Question(s): 5, 6

h) Remote Sensing

Objective: To develop techniques to identify forest stress using remote sensing.

Anticipated Results: A method for mapping and assessing injury including tree decline in forest stands could be available to determine the extent and severity of the problem economically and routinely over larger areas of the Province.

Achievements: Moniteq Ltd. of Concord, Ontario has been contracted to map stressed forests in Ontario and in West Germany using unique airborne remote sensing methods. Special imagery provides digital electronic data which can be computer processed to produce images for forest stress. In Ontario, flights were made in August, 1985 near Thunder Bay, Magnetewan (north of Muskoka) and the Gibson Indian Reserve near Parry Sound. During July-August, 1986, flights were made over heavily stressed forests in West Germany and staff of the Ontario Ministry of the Environment participated in the testing of equipment and "ground-truthing" of the areas examined. Additional remote sensing activities using new assessment photographic techniques were undertaken in 1987.

Scientific Questions(s): 2

i) White Birch Decline

Objective: To determine the role of precipitation chemistry in the decline of white birch trees on the east shore of Lake Superior.

Anticipated Results: A preliminary assessment of the chemistry of fog will be made and compared to that of the fog found in the area along the north shore of the Bay of Fundy in New Brunswick where problems with white birch have occurred in recent years. The data can also provide a comparison for data obtained under the Chemistry of High Elevation Fogs (CHEF) program which is examining the role of fog chemistry in dieback of tree species at the tops of mountains in eastern U.S.A. and Quebec.

Achievements: White birch trees on the east shore of Lake Superior are currently undergoing extensive dieback over a large area. Preliminary studies into the situation were carried out by staff of the Northeast Region in 1984 and 1985. Further studies will be carried out in 1988 to examine the chemistry of the fog which is known to occur with high frequency in that area.

Scientific Questions(s): 1, 2

In summary, the Ontario Ministry of the Environment has established a program to systematically investigate the potential effects of pollutants from long-range sources (acidic precipitation and oxidants) on the terrestrial environment. The program is organized through the Terrestrial Effects Working Group under the Acidic Precipitation in Ontario Study (APIOS). The program includes various component studies to examine the effects of pollutants on soil and vegetation, and to determine whether decline of forest species is related to these pollutants. By performing these studies, it should be possible to document the role of pollutants on the terrestrial environment in order to adequately address future abatement strategies to protect the environment.

APPENDIX 1

Factors Directly Affecting Sensitivity to Pollutants

Plant

- species
- age
- plant organ
- nutrition
- accumulation in tissues
- temperature
- relative humidity
- soil moisture
- dose of pollutant
- surface wettability
- physiological tolerance
- nutrient and energy reserves
- season
- morphology
- tolerance to disease and insects
- genetic variability

APPENDIX 2

Factors Indirectly Affecting Sensitivity to Pollutants

Soils	- soil pH
	- soil buffering (CO_3)
	- available nutrients and elements (metals)
	- imbalance of nutrients
	- soil structure
	- soil texture
	- depth
Biotic	- disease
	- insects and other pests
	- mycorrhizae
	- nodulation
	- allelopathy
	- competition

APPENDIX 3

Measures of Impact of Pollutants

Growth - height
- number of leaves, branches
- mass of individual organs
- diameter and ring widths
- leaf area
- tissue strength
- number of stomates

Chemistry - accumulated elements
- stored energy (sugar, starch, lipid)
- pigments
- buffering capacity
- nitrogen and protein storage
- enzymes
- other organic compounds

Physiological - winter hardiness
- gas exchange
- respiration
- photosynthesis
- water potential

Other - cuticular erosion
- cuticular composition
- reproduction

APPENDIX 4

Plant Species of Primary Concern

Crop Species

- Soybean
- Corn
- Alfalfa
- Wheat
- Oats
- Clover
- Tomatoes
- Potatoes
- Beans

Forest Species

Hardwoods - Sugar Maple
Yellow Birch
White Birch
Silver Maple
Ash
Hybrid Poplar

Softwoods - White Pine
- White Spruce
- Hemlock
- Norway Spruce

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